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Renewable energy from agro-residues in China: Solid biofuels and biomass briquetting technology

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A B S T R A C T

China has the abundant agro-residue resources, producing more than 630 million tons of agro-residues in 2006, and amounting to about 20% of total energy consumption in rural areas. Efficient utilization of enormous agro-residues resource is crucial for providing bioenergy, releasing risk of environmental pollution, and increasing farmers' income. The paper presented the feasibility of densified solid biofuels technology for utilizing agro-residues in China. The output and distribution of agro-residues in recent 10 years, the R&D of briquetting technology, and the market of densified solid biofuels from agro-residues in China have been analyzed. The result indicated that the abundant agro-residue resources can provide the economical and sustainable raw material for densified solid biofuels development in China. The R&D of briquetting technology at present can strongly support the large scale production of densified solid biofuels. With continued improvement and cost reduction of briquetting technology, along with the support of nation energy policy on biomass energy, the market of densified solid biofuels from agro-residues in China will be more fully deployed. Based on the above mentioned key factors, development of densified solid biofuels from agro-residues in China will be promising and feasible.

Contents

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1. Introduction

Biomass is the third largest primary energy in the world, after coal and oil [1]. It remains the primary source of energy for more than half the world's population, and provides about 1250 million tons oil equivalent (Mtoe) of primary energy which is about 14% of the world's annual energy consumption [2–4]. Correctly managed, biomass is a renewable and sustainable fuel that can deliver a significant reduction in net carbon emissions when compared with fossil fuels. It is therefore likely to be an attractive clean development mechanism (CDM) option for reducing greenhouse gas (GHG) emission [5].

Agricultural residues constitute one of the important biomass feedstocks in China, due to its vast agricultural base. At present direct combustion of agricultural residues is the main utilization of biomass energy in China, particularly in rural areas, which leads to many problems. On the one hand, the direct burning of loose biomass in conventional grates is associated with very low thermal efficiency, and therefore wastes energy resources. The conversion efficiencies are as low as 40% with particulate emissions in the flue gases in excess of 3000 mg/Nm^3 [6]. On the other hand, direct combustion for cooking and heating in rural areas typically brings with its detrimental effects of indoor air pollution and associated adverse health impacts. Clear and efficient energy derived from agricultural residues will improve access to energy for rural isolated households, improve indoor air quality, and contribute to rural development by increased household income. This economic, environmental, and social context promotes the use of efficient and modern technologies on biomass energy conversion of agricultural residues. One of the main technologies is biomass briquetting technology which converts loose agricultural residues to densified solid biofuel [3]. The briquetting technology improves the characteristics of agro-residues for transportation, storage, feeding into furnaces, and combustion.

For exploring the potential and feasibility of densified solid bi-fuel from agricultural residues by biomass briquetting technology in China, this article discusses the following issues: (a) the output and distribution of agricultural residues in China; (b) problems associated with densified solid biofuel from agricultural residues; (c) biomass briquetting technology in China; (d) the market for solid biofuels from agricultural residues in China.

2. Yield and distribution of agricultural residue resources in China

2.1. Yield

Although the production of agricultural residues cannot be directly obtained from statistical yearbook, it can be estimated from the product yield of crops and residue to crop ratio. The yield of main crops from 1995 to 2006 is obtained from China statistical yearbook [7] (Table 1). Residue to crop ratio for main Chinese agricultural crops has been studied by MAO/DOE Project [8]. The estimated yield of agricultural residues is shown in Fig. 1. The three largest contributions to the total output of agricultural residues were from corn, wheat, and rice. The three kinds of agricultural residues accounted for more than 75% of the total agricultural residue resources. The lowest output was 579.35 million tons in 2003. The highest output was 687.56 million tons in 2006. The average output from 2000 to 2006 was 623.66 million tons. Currently, these agricultural residues have four uses [9,10]: as industrial material, mostly for papermaking; as fertilizer returned to the field; as livestock feeding; and as fuel (Table 2). The amount of agricultural residues available as fuel accounted for about 54s 336.78 million tons. The best estimate suggests that consumption as fuel is about 168 million tons coal equivalent (Mtce) [8,10]. Therefore, there is great potential for the development of densified solid biofuel from agricultural residue in China.

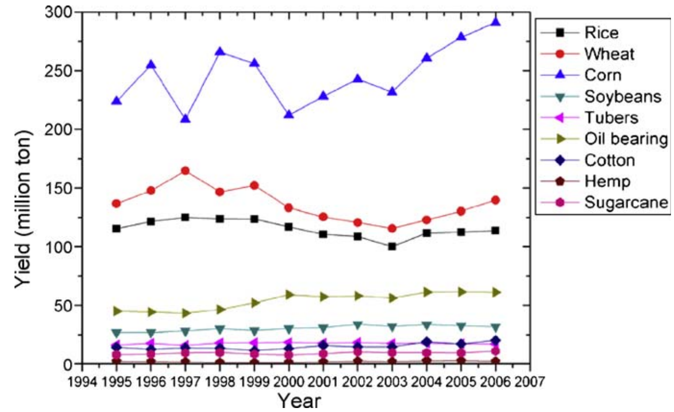


Fig. 1. Trends in the yield of major agricultural residues in China [7].

Table 2
Main routes for agricultural residues utilization in China [10].

Route	Proportion (%)
Raw material in industry	3.29
Fertilizer	15
Livestock feeding	28
Fuel	53.71

2.2. Distribution

The distribution of crops is distinct in different regions of China because the country has a complex physical geography and social

Table 1
The yields of main agricultural crops in China from 1995 to 2006[a] (Unit: 10^6 tons).

Crops	Residue to crop ratio[b]	Yields											
		1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Rice	0.623	185.23	195.10	200.73	198.71	198.49	187.91	177.58	174.54	160.66	179.09	180.59	182.57
Wheat	1.336	102.21	110.57	123.29	109.73	113.88	99.64	93.87	90.29	86.49	91.95	97.45	104.47
Corn	2	111.99	127.47	104.31	132.95	128.09	106.00	114.09	121.31	115.83	130.29	139.37	145.48
Soybeans	1.5	17.88	17.90	18.76	20.01	18.94	20.10	20.53	22.41	21.28	22.32	21.58	21.04
Tubers	0.5	32.63	35.36	31.92	36.04	36.41	36.85	35.63	36.66	35.13	35.58	34.69	34.06
Oil bearing	2.0	22.50	22.11	21.57	23.14	26.01	29.55	28.65	28.97	28.11	30.66	30.77	30.59
Cotton	3.0	4.77	4.20	4.60	4.50	3.83	4.42	5.32	4.92	4.86	6.32	5.71	6.75
Hemp	2.5	0.90	0.79	0.75	0.50	0.47	0.53	0.68	0.96	0.85	1.07	1.10	0.89
Sugarcane	0.1	79.40	83.60	93.86	97.90	83.34	76.35	86.55	102.93	96.42	95.71	94.52	110.32
Total	–	557.49	597.11	599.80	623.48	609.45	561.34	562.90	582.99	549.62	592.99	605.77	636.18

[a] *Source*: China Statistical Yearbook [7].
[b] *Source*: MAO/DOE Project [8] except Hemp [4].

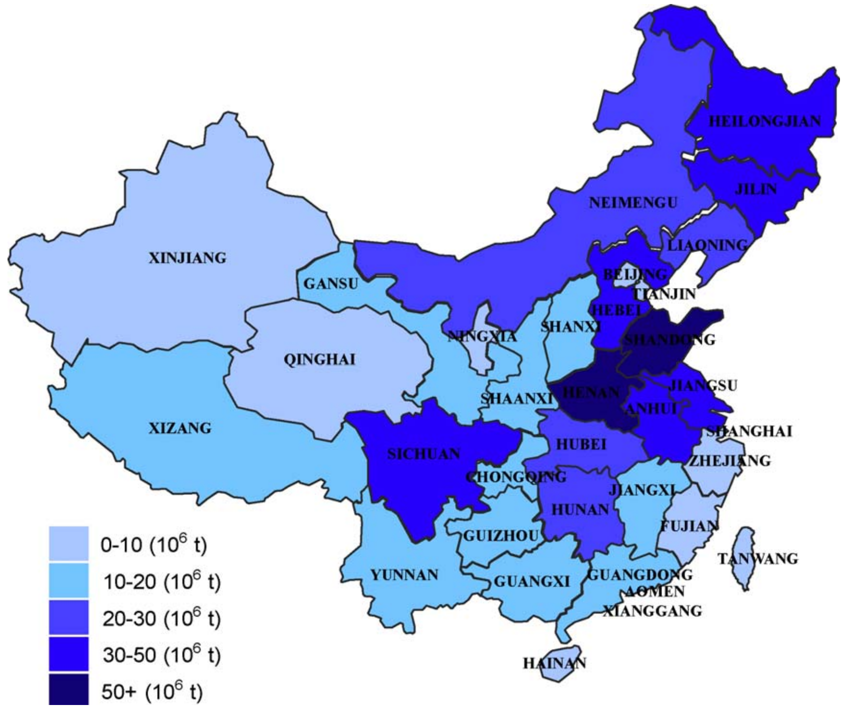


Fig. 2. The distribution of the average output of agricultural residues during 2000–2006 in China [7].

economy. It is an important factor for energy policy framing and efficient utilization of agricultural residues. The distribution (average value) of main agricultural residues during 2000–2006 in China is shown in Fig. 2 and Table 3 [7].

The mainland of China may be divided into six regions: North, Northeast, East, Central south, Southwest, and Northwest of China. The distribution amount of agricultural residues in the six regions is 87.51, 99.49, 157.70, 149.23, 78.32, and 51.42 million tons, respectively. The three provinces comprising the most abundant agricultural residues are Henan (70.10 million tons), Shandong (66.21 million tons), and Hebei (43.57 million tons), respectively. The corn and wheat residue are their most main constituents, which account for about 80% of total production. The rice residue mainly came from Central south (Jiangsu, 10.49 million tons; Jiangxi, 9.62 million tons) and Southwest (Hunan, 14.07 million tons; Hubei, 9.19 million tons).

3. Problems associated with densified solid biofuel from agricultural residues

Unlike conventional energy feedstock, agricultural residues have complex physicochemical properties which complicate the processing and combustion of densified solid biofuel from agricultural residues. These physicochemical characteristics may include moisture content, ash content, and flow characteristics.

3.1. Moisture content

The moisture contents of agricultural residues are usually related with the process of separating the residues from the crop product [3]. The moisture contents of most agricultural residues were listed in Table 4 [11]. It is indicated that different parts and different catalogues of agricultural residues have distinct moisture content. Moisture content should be as low as possible, generally in the range of 10–15%. High moisture content will pose problems in firing and excessive energy is required for drying. Huge moisture content can lead to reduce the combustion temperature, hinder the combustion of reaction products and consequently affect the quality of combustion [12].

3.2. Ash content

The ash content of some types of agricultural residues is given in Table 4 [11]. The ash content varies from one residue to another. The ash content of the rice straw and husk is more than 18%. The ash content and composition greatly affect the tendency to slagging behavior. The agricultural residues with high ash content usually comprise the abundant alkaline earth metals. These constituents have low fusion temperature which leads to an increase in the slagging potential [3]. There can also be a tendency for the low melting components of agricultural residue ash to sinter and form fused or partly fused slag deposits on the walls of the furnace. Agricultural residues with less than 4% ash content are preferred for briquetting because non-slagging takes place in these densified solid biofuels [6].

3.3. Flow characteristics

Most of agricultural residues have poor flow characteristics which may cause post-processing problems, such as briquetting. Particle size and shape have important effect on flow characteristics [13]. The granular (preferably 6–8 mm in size) homogeneous materials which can flow easily in conveyors, bunkers and storage silos, are suitable for briquetting [6,14].

4. Briquetting technologies in China

The briquetting technology can convert loose agricultural residues into high density solid biofuel which is easy to lighten, conventional to use, has high burning efficiency and low pollution. The densification of biomass without binder can be contributed to their natural binders such as protein and lignin [15,16]. The presence of lignin in the biomass can enhance the binding

Table 3
The distribution (average value) of main agricultural residues during 2000–2006 in China (Unit: 10^6 tons) [7].

Regions	Rice	Wheat	Corn	Soybeans	Tubers	Oil-bean	Cotton	Hemp	Sugarcane	Total
North of China										
Beijing	0.02	0.43	1.06	0.05	0.01	0.07	0.01	0.00	0.00	1.65
Tianjin	0.07	0.61	1.34	0.08	0.00	0.05	0.24	0.00	0.00	2.39
Hebei	0.32	14.89	22.27	0.91	0.56	3.06	1.51	0.02	0.03	43.57
Shanxi	0.01	3.12	9.92	0.68	0.39	0.59	0.27	0.00	0.01	14.99
Neimengu	0.37	1.74	17.72	1.93	0.83	2.15	0.01	0.03	0.14	24.91
Northeast of China										
Liaoning	2.42	0.18	18.54	0.79	0.27	0.90	0.01	0.00	0.02	23.13
Jilin	2.53	0.10	31.63	2.40	0.26	0.94	0.00	0.01	0.03	37.89
Heilongjiang	6.48	1.12	19.19	9.17	0.51	0.99	0.00	0.78	0.22	38.47
East of China										
Shanghai	0.64	0.16	0.06	0.04	0.00	0.19	0.00	0.00	0.01	1.11
Jiangsu	10.49	9.52	4.41	1.45	0.38	4.42	1.13	0.01	0.03	31.84
Zhejiang	4.74	0.39	0.46	0.67	0.32	1.01	0.07	0.00	0.10	7.77
Anhui	7.60	10.19	5.71	1.77	0.77	5.51	1.01	0.09	0.03	32.68
Fujian	3.47	0.07	0.24	0.38	0.77	0.53	0.00	0.00	0.10	5.56
Jiangxi	9.62	0.05	0.12	0.43	0.28	1.64	0.24	0.03	0.11	12.53
Shandong	0.62	22.72	30.64	1.22	1.23	7.22	2.54	0.01	0.00	66.21
Central south of China										
Henan	2.00	32.37	22.79	1.54	1.15	8.07	2.08	0.09	0.03	70.10
Hubei	9.19	2.66	3.85	1.01	0.83	5.64	1.09	0.14	0.07	24.47
Hunan	14.07	0.23	2.53	0.88	0.81	2.72	0.56	0.31	0.13	22.25
Guangdong	7.51	0.03	1.22	0.37	0.96	1.57	0.00	0.00	1.21	12.88
Guangxi	7.42	0.03	3.60	0.61	0.31	1.18	0.00	0.03	4.59	17.77
Hainan	0.88	0.00	0.11	0.04	0.19	0.19	0.00	0.00	0.36	1.77
Southwest of China										
Chongqing	3.03	1.15	4.14	0.46	1.26	0.74	0.00	0.03	0.01	10.82
Sichuan	9.26	6.01	10.55	1.63	2.30	4.20	0.09	0.13	0.15	34.32
Guizhou	2.80	1.10	6.69	0.59	1.01	1.56	0.00	0.00	0.07	13.82
Yunnan	3.81	1.69	8.97	1.11	0.85	0.63	0.00	0.15	1.59	18.80
Xizang	0.00	0.37	0.03	0.05	0.00	0.10	0.00	0.00	0.00	0.55
Nothwest of China										
Shaanxi	0.54	5.45	8.07	0.51	0.39	0.84	0.18	0.00	0.00	15.98
Gansu	0.03	3.71	4.53	0.58	0.78	0.90	0.28	0.03	0.03	10.87
Qinghai	0.00	0.56	0.02	0.15	0.13	0.51	0.00	0.00	0.00	1.37
Ninxia	0.37	1.08	2.18	0.10	0.12	0.21	0.00	0.00	0.00	4.06
Xinjiang	0.34	5.05	6.65	0.38	0.06	0.90	5.07	0.27	0.41	19.13

Table 4
The moisture and ash contents of agricultural residues[a].

Crop	Residue	Moisture content (%)	Ash content[b] (%)
Rice	Straw	15.5	18.1
Rice	Husk	10.4	19.5
Corn	Stalk	16.8	10.0
Corn	Cob	7.7	8.1
Corn	Husk	11.0	1.2
Wheat	Straw	14.6	12.8
Millet/Rye/Oats	Straw	15.0	na
Barley	Straw	16.3	4.3
Sorghum	Straw	15.0	na
Cassava	Stalk	15.0	na
Groundnut	Husk/Shell	7.8	na
Groundnut	Straw	12.0	1.3
Soybean	Straw	15.0	na
Sugar cane	Bagasse	49.8	6.0
Sugar cane	Tops/Leaves	62.5	1.2
Cotton	Stalk	12.0	9.4
Cotton	Husk	10.0	6.0
Coconut	Shell	10.9	1.0
Oil palm	Shell	7.3	4.0
Oil palm	Fibre	36.7	5.0
Oil palm	Empty bunches	36.7	5.0
Coffee	Husk	15.0	na

[a] *Source*: Koopmans and Koppejan [11].
[b] na denotes not available.

characteristics of densified banquette during the preheating of the material. Lignin has a low melting point of about 140 °C. When biomass is heated, lignin becomes soft and sometimes melts and exhibits thermosetting properties [17]. Protein also plays a major role as a binding agent between different particles during compaction. Protein denaturation and plasticization during densification may positively affect the hardness and durability of the banquette [18]. Upon cooling, the protein reassociates and bonds can be established between different particles. In China, there are a number of studies on briquetting device and technology.

4.1. Briquetting device

At present, the industry of biomass briquetting device in China has formed primary scale. The main types of briquetting device developed in China has been summarized by previous researchers [4] and may be divided into piston press, screw press, hydraulic press, and roller press.

4.1.1. Mechanical piston press

Also known as ram and die technology, the biomass is punched into a die by a reciprocating ram with very high pressure, therefore compressing the mass to obtain a briquette. The piston press has long life of wearing parts and low power consumption. It can be

Table 5
Main R&D activities of briquetting technology in China.

Stage	Project title	Project type[a]	Project organizer[b]
Pre-1995	Limited national project is funded	–	ICIFP, LNIER CAAMS, CAAE
1995–2005	Experimental study of agricultural material briquetting	NSFC (Project No. 59365004)	NMGAU
	Rheodynamic characteristics of herbage materials in compression and optimization of compression process	NSFC (Project No. 59865001)	NMGAU
	Experimental study on the optimization of compression process of fresh forages	NSFC (Project No. 50165001)	NMGAU
	The study of biomass briquetting equipment	National Key Technologies R&D Program in the Ninth Five-Year Plan	LNIER
	The study of biomass briquetting key techniques and relative equipment	National Key Technologies R&D Program in the Tenth Five-Year Plan (Project No. 2001BA403B04)	HNAU
	Assembling and testing of biomass (straw) briquetting equipments	Fund for Transformation of Scientific and Technological Achievements in Agriculture (Project No. 02EFN214100397)	HNAU
Post-2005	Study on biomass solid biofuels and equipment	National Key Technologies R&D Program in the Eleventh Five-Year Plan	JSZCCFM Co. LTD.
	Study and import of the standard for solid biofuels	948 Project of Chinese Ministry of Agriculture	CAAE
	Study on equipment and production process of solid biofuels	Fund for Transformation of Scientific and Technological Achievements in Agriculture	CAAE

[a] NSFC, National Natural Science Foundation of China.
[b] ICIFP, Institute of Chemical Industry of Forest Products; LNIER, Liaoning Institute of Energy Resource; CAAMS, Chinese Academy of Agricultural Mechanization Sciences; CAAE, Chinese Academy of Agricultural Engineering; NMGAU, Neimenggu Agricultural University; HNAU, Henan Agricultural University; JSZCCFM Co. LTD., Jiangsu Zhengchang Cereal and Feed Machinery Co. LTD.

used to compress a wide range of raw biomass materials which include corn straw, peanut shell, ground nut shell, cotton stalks, sun flower stalks, etc. However, the piston press needs a higher level of maintenance and the briquettes has lower quality and cannot be carbonized if compared to the screw press.

4.1.2. Screw press

In a screw press the biomass is extruded continuously through a heated taper die, which is heated externally to reduce the friction. The advantages of screw press are high quality of briquettes (superior storability and combustibility), smooth and noiseless operation. The two major impediments for the screw press: high wear of the screw and the comparatively large specific power consumption required.

4.1.3. Hydraulic press

In this type of press, the energy to the piston is transmitted from an electric motor via a high pressure hydraulic oil system. Because of the slower press cylinder compared to that of the mechanical machine, it results in lower outputs, but it can tolerate higher moisture content of agricultural residues.

4.1.4. Roller press

Roller press uses smaller dies (approximately 30 mm) so that the smaller products are called pellets. It has a number of dies arranged as holes bored on a thick steel disc or ring, and the material is forced into the dies by means of two or three rollers. The two main types of pellet presses are: flat type, which has a circular perforated disc on which two or more rollers rotate, and ring type, which features a rotating perforated ring on which rollers press onto the inner perimeter.

4.2. Research and development (R&D) of biomass briquetting technology

The study of biomass briquetting technology in China can be traced back to around 20 years ago since Institute of Chemical Industry of Forest Products (ICIFP) carried out the research on biomass briquetting technology during China's Seventh Five-Year Plan (1986–1990). The R&D of biomass briquetting technology in China can be divided into three stages. Before 1995, focuses are basic technology development. Since 1996 and on to 2005, the first generation technology is implemented to promote the small scale industry. Beyond 2005, biomass briquetting technology will aim to improve and upgrade to apply to large scale industry. Main R&D activities at the national-lever of briquetting technology in China are listed in Table 5.

4.2.1. Pre-1995

During China's Seventh and Eighth Five-Year Plan (1986–1995), some institutions (ICIFP, Chinese Academy of Agricultural Mechanization Sciences, Liaoning Institute of Energy Resource, and Chinese Academy of Agricultural Engineering) contributed to the study of biomass briquetting technology. In this stage, the study focuses on basic technology development. A few prototype briquetting equipments were developed, such as ZT-63 biomass briquetting device (Food processing machine company, Hengyang city, Hunan province) and OBM-88 briquetting device for bar-formed solid biofuel (Donghai food processing machine company, Lianyungang city, Jiangsu province).

4.2.2. 1996–2005

During China's Ninth and Tenth Five-Year Plan (1996–2005), this is a fruitful stage for the study of both briquetting device and biomass compression theory. National Natural Science Foundation of China (NFSC) funded continuously the research project on biomass compression mechanism conducted by Neimenggu Agricultural University. The project systemically studied the mechanical behavior of different biomass materials at all stages of their compression process. These mechanical behaviors include rheological property, stress-strain relationship, relaxation property, specific energy required property, pressure-density relationship, etc. In this stage, the study of briquetting device also attracts interesting of many institutions and universities. Based on the first generation technology, these R&D institutions develop some commercial briquetting machines for suiting the small scale industrialization. The typical case is the study of HPB series briquetting machines which are funded by National Key Technologies R&D Program in the Tenth Five-Year Plan (2001–2005) and Foundation for Transformation of Scientific and Technological

Achievements in Agriculture. The objectives of the two projects are to develop briquetting equipment with higher productivity, lower energy consumption, and longer life of wearing parts. At present, HPB series briquetting equipment has been commercialized and became one of leading commercial briquetting equipments in China market.

4.2.3. Post-2005

Renewable and clean energy is the inevitable choice for sustainable economic growth, for the harmonious coexistence of human and environment as well as for the sustainable development. Biomass resources as clean and renewable energy source are abounding in China. In order to promote and ensure the rapid, effective and sustainable development of biomass energy, China launched some key projects on R&D of biomass energy in China's Eleventh Five-Year Plan (2006–2010). The R&D of biomass briquetting technology is one of these key projects. National Key Technologies R&D Program in the Eleventh Five-Year Plan funded 44 million RMB (investment including nation, province and organizing enterprise) to support R&D of densified biofuel technology and equipment. The study content of this project focus on: (a) the effect of pre-processing on biomass densified properties; (b) explore the binding mechanism of biomass densification; (c) develop briquetting technology which can process a wide range of biomass material; (d) develop briquetting device with high productivity and low energy consumption; (e) establish demonstration project of densified biofuel (3000 tons/year) using agro-forest residues as raw materials. For promoting the large scale commercialization of densified biofuel, the study on the standard for solid biofuel has been funded by 948 Project of Chinese Ministry of Agriculture. In China's Eleventh Five-Year Plan, the government has set the targets that the annual consumption of densified biomass biofuels around the country will reach 1 million tons by 2010. Therefore, the R&D aim of this stage focuses on upgrading biomass briquetting technology to quicken the steps of solid biofuels development, which can not only provide clean and renewable energy, but solve efficient utilization of agricultural residues in China.

5. Markets for solid biofuels from agricultural residues in China

The economization, availability and sustainability of raw material, and extensive needs are key factors for any industry market. In China, solid biofuels industry using agro-residues as raw material possesses these essential characteristics which are in favor of its successful market. Firstly, agro-residues in China have low price. Agro-residues are often discarded, even burned in the fields, which makes waste of resource and pollution of environment. Secondly, agro-residues in China are abounding, which has been detailedly described in Section 2. Thirdly, agro-residues are renewable organic matter that can be used as sustainable energy resource. Finally, solid biofuels is urgently and extensively needed in China, especially in rural areas. China has a large population, 70% of which lives in rural areas. In 2005, representing one-fifth of total rural energy consumption came from agro-residues [19,20]. In addition, the amount of rural energy consumption from agro-residues presented an increasing trend from114.88 Mtce in 1998 to 159.59 Mtce in 2005 (Fig. 3). Developing biomass energy from agro-residues can (a) provide clean and sustainable energy for rural areas, (b) promote economic development in rural areas, (c) enhance rural incomes, (d) accelerate industrialization of agriculture and small and medium town construction, and (e) reduce risk of environmental pollution [10]. The modern technologies of converting solid biomass into high quality energy carriers can be broadly classified as densified solid biofuels, gasification, biomass pyrolysis, anaerobic digestion, landfill gas, physical–chemical conversion, fermentation and hydrolysis [21]. Based on the real situation of China, developing solid biofuels industry is more favorable compared to other technologies. Firstly, densified solid biofuels from agro-residues are often the accessible and affordable energy, particularly in rural areas. Secondly, densified solid biofuels from agro-residues have a wide range of application. It can be used as fuel for cooking and heating farm households, as fuel for decentralized heating in urban areas, and as fuel for power industries due to its advantages of easy storing, transporting and usage, as well as clean and high combustion efficiency. The priorities for power development of densified solid biofuels have been described in Medium and Long-Term Development Plan for Renewable Energy in China [10]: (a) by 2010, 500 pilot rural areas using densified solid biofuel will be established. The annual consumption of densified solid biofuel will reach 1 million tons, most of which are used as rural and urban households fuel and commercial fuel product for industry; (b) by 2020, the annual consumption of densified solid biofuel will reach 50 million tons. The production of solid biofuel consist of two main ways: one is in small scale production in rural areas; the other way is large scale production in suitable areas. The former mainly used as household in rural areas, whereas the latter is used as commercial fuel for industrial users and urban residents. The market of agro-residues briquetting industry will be very promising due to its close relation to energy, the environment and the important issues of agriculture, rural areas, and rural residents.

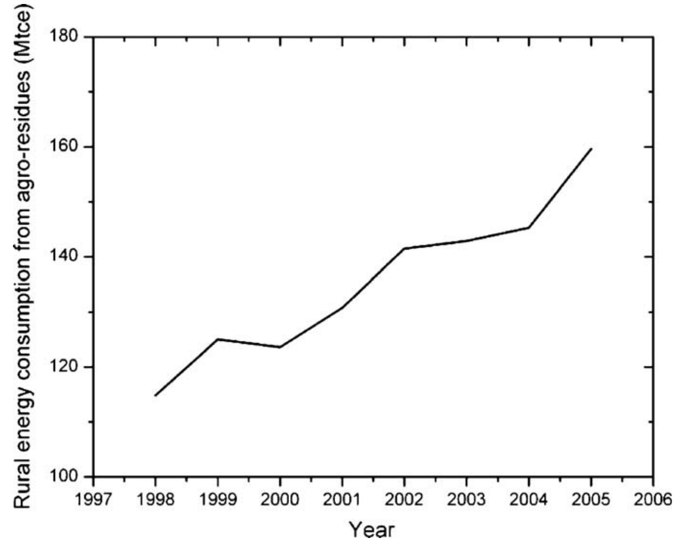


Fig. 3. Rural energy consumption from agro-residues during 1998–2005 in China.

6. Conclusions

China has enormous agro-residue resource. The output and distribution of agro-residues in recent 10 years has been analyzed. The result indicated that the output of agro-residues in China is increasing and reaches 636.18 million tons in 2006. The three provinces comprising the most abundant agricultural residues are Henan (70.10 million tons), Shandong (66.21 million tons), and Hebei (43.57 million tons), respectively. However, such enormous resources in China, particularly in abundant distribution provinces, need highly efficient and recycling utilization, which is crucial for providing bioenergy, releasing risk of environmental pollution, and increasing rural income.

Based on the real situation of China, densified solid biofuel could be one important route of agro-residues efficient utilization. The R&D of briquetting technology and the market of densified solid biofuels from agro-residues in China have been analyzed.

Although at present briquetting technology in China has not yet reached full maturity and there is considerable scope for design improvements which will lead to extended life of wearing parts and reduced energy consumption for the briquetting of agro-residues, it has provided a basis for further development of densified solid biofuels in China. In China's Eleventh Five-Year Plan, the R&D of briquetting technology obtains strong support and aims to achieve the large scale production of densified solid biofuels. With continued improvement and cost reduction of briquetting technology, along with the support of nation energy policy on biomass energy, the market of densified solid biofuels from agro-residues will be more fully deployed.

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